Economic Linkages Between Coastal Wetlands and Water Quality: A Review of Value Estimates Reported in the Published Literature

Richard F. Kazmierczak, Jr.
Associate Professor of Environmental Economics
Department of Agricultural E

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Richard F. Kazmierczak, Jr.
Louisiana State University Agricultural Center

Summary

This manuscript summarizes a total of 12 peer-reviewed studies,[1] published from 1981 to 2001, reporting 28 separate estimates for the disaggregate[2] value of water quality services provided by coastal and non-coastal wetlands. Estimates ranged across three orders of magnitude and are highly dependent on the specific geographic site providing the service, the type of water quality service provided, the measurement technique, and whether locally derived benefits were calculated to extend across all existing wetlands. Considering only coastal zone wetlands across all study categories, the value of water quality services ranged from $2.85/acre/year to $5,673.80/acre/year, with a mean and median of $825.04/acre/year and $210.93/acre/year, respectively.[3, 4] The large difference between the mean and median value reflects the non-normal distribution of the estimates, and in particular the influence of a few very high values. Eliminating the most extreme outliers from the calculations generated mean and median values of $323.05/acre/year and $178.64/acre/year, respectively. By comparison, reported estimates of willingness-to-pay (WTP) values for wetland water quality services were relatively consistent across studies,[5] ranging from $41.71 to $101.81, with a mean and median of $66.59 and $63.19, respectively. The apparent importance of geographic location, and the specific use demand, on water quality service value suggests that this facet of coastal wetland benefits needs to be carefully examined within a spatially disaggregated context.

Introduction

Coastal wetlands are increasingly recognized as essential to natural systems and human activities because of the environmental services that they provide. However, this recognition has not resulted in capitalized economic value for landowners (Heimlich et al. 1998). Nonmarketed wetland benefits may be important to society, but the lack of a market value for the services means that they are often de-

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[1] To the author's knowledge this represents all the peer-reviewed published studies that explicitly seek to value the linkage between wetlands and water quality/purification services.

[2] From a theoretical economic perspective, the services provided by wetlands generally should not be disaggregated and valued separately due to the potential for double counting and offsetting effects (see Pendleton and Shonkwiler [2001] for a discussion of this in a different context). For example, the provision of water purification services may, in many cases, simultaneously provide for increased habitat and species protection. Valuing each of these services separately (when, in fact, they are inseparable) and summing will lead to overestimating total potential wetland value.

[3] All values in year 2000 dollars (see Table 1).

[4] In a partial review of wetland valuation studies, Heimlich et al. (1998) calculated a much broader range on the per acre value estimates, in part because they considered the provision of a number of different services besides water quality, but also because they converted household and individual willingness-to-pay (WTP) values to per acre values using various assumptions not necessarily contained in the original studies. The review presented in this manuscript does not take this approach, and instead lists the WTP values separately (if not originally presented on a per acre basis) for comparison purposes.

[5] Note that the WTP estimates were not, in general, estimated on a per acre basis, and thus should not be directly compared with the per acre values estimated from non-WTP studies.

emphasized relative to physical loss or the private economic gains that can arise from conversion of wetlands to other land uses (van Vuuren and Roy 1993). While the search for quantitative measures of wetland values is challenging due to the diversity, socioeconomic context, and complex hydro-biological functions of wetlands (Scodari 1990), informed policy requires that both market and nonmarket wetland values be incorporated into the decision making process.

One of the most important, but usually nonmarketed, services provided by coastal wetlands is water quality control, and in particular the retention, removal, and transformation of nutrients. Numerous studies have shown that natural and constructed wetlands can be effective tertiary processors of wastewater effluent (Richardson and Davis 1987; Conner et al. 1989; Reed 1991; Kadlec and Knight 1996). Efficient at removing excess nutrients and pollutants, wetlands and their environmental services may be especially critical in coastal Louisiana and the Northern Gulf of Mexico for the mitigation of degraded water flowing south through the state (Louisiana DEQ 1988; Doering et al. 1999). The value of this service comes in the form of reduced costs of water purification, where the water is used in production and consumption, or reduced contamination where the water continues to reside in the environment. As with most types of pollution, however, the economic damages associated with water quality impairment, and thus the value of the purification services performed by wetlands, are difficult to measure. Thus, the key economic issue is to establish the value to water quality of an acre of coastal wetland preserved, restored, enhanced or created.

This report documents the current status of knowledge concerning the economic value of the water quality services generated by coastal and other wetlands. In particular, studies that focus on valuing water purification services as an unbundled product of wetland function are highlighted.[6] A brief overview of the theoretical economic linkages between wetland ecosystems and water quality is first presented, thus providing a basic framework for understanding why specific variables and measurement methods are of interest. Second, the common methods used to value the water quality services of wetlands are outlined, along with their major advantages and disadvantages. This information can help the reader evaluate the usefulness of any particular estimate. Next, the results of individual water quality service valuation studies are presented and summarized. Lastly, the report concludes with a complete list of the literature cited.

Relationship Between Wetlands and Water Quality

Policymakers face complex, multi-objective trade-offs when attempting to develop strategies for coastal restoration and protection.[7] Implementation of any specific strategy will result in benefits and costs that will, in general, be different than those experienced under alternative strategies. Economics can be used to help inform policymakers about the relative benefits and cost of different strategies, but analysts require information on (1) the relationship between anthropogenic activities and coastal wetland loss, (2) the costs imposed on society from coastal wetland loss, and (3) the costs of taking action to prevent coastal wetland loss. In the typical environmental management scenario, human activities are considered to be a cause of degradation, and the management of these activities via regulation or the use of economic instruments has the goal of reducing environmental impacts. Changing established human activities is potentially costly, and the cost will vary by the specific type of activity and its interrelationship with the environment. While some Louisiana coastal wetland loss can be attributed to traditional human industrial, municipal, and agricultural activities, natural environmental processes on a regional, hemispheric, and

[6] A substantial part of the wetland valuation literature attempts to measure the theoretically correct multi-product value of wetlands and not the individual service components. An overview of the results generated by these studies is presented in the report (Table 2) for comparison to the single-product water quality value estimates.
[7] The following discussion was adapted from Keithly and Ward (2001).

global scale are also important. Complicating the identification of causal linkages and their importance to water quality is the heterogeneity of existing wetlands. Some wetlands perform many functions, but some may perform few or even none. In addition, many of the environmental services are generated simultaneously in varying degrees by the same wetland function. From this perspective, water purification and/or quality preservation services of wetlands can best be understood as part of an economic joint product. This jointness-in-products creates difficulties in measuring the economic importance of specific wetlands functions, and as a result the literature contains a limited number of empirical studies that isolate the water quality costs (foregone benefits) imposed on society from wetland loss.

Abstracting from the technical measurement difficulties, there are a number of general benefits that accrue to society from its interaction with any large-scale ecosystem such as coastal wetlands (Pearce and Turner 1990). Ecosystems supply both stock and flow resources that can be used as direct and indirect inputs to production and consumption activities, thereby generating productivity and growth in the overall economic system. While the resources can be either renewable or nonrenewable, goods and services provided by Louisiana's coastal wetlands (and their associated marine ecosystems) are generally considered renewable resources.[8] The provision of quality water via purification processes can be considered one of these renewable resources, and it is tied to a second benefit, the ability of coastal wetlands to assimilate wastes. As long as the waste flow into the ecosystem is below its assimilative capacity, the ecosystem is able to turn the wastes into harmless and/or ecologically useful products. On a regional scale, however, assimilation capacity is dependent of the amount and distribution of the ecosystem in relationship to the waste sources. For Louisiana's coastal wetlands, potential demands for water purification are in part diffuse, but also highly concentrated in some areas (particular for municipal wastewater treatment). Lastly, a benefit arises because ecosystems provide a source of utility that is independent of its direct consumptive uses. This utility, derived through the biological and cultural diversity of ecosystems, is generated by coastal wetlands through non-consumptive use activities (such as viewing) and knowledge that the functioning ecosystem exists. Water quality is an integral component of this last source of benefits from coastal Louisiana wetlands.

Once the benefits of an ecosystem are identified, economic values need to be assigned to these benefits. Having these assigned values allows policy makers to quantitatively assess the economic benefits that society might gain from marginal improvements in the integrity of the ecosystem. Value is associated with the amount that society (both current and future generations) would be willing to pay for the services and attributes provided by the ecosystem if they were not provided free of charge. The greater the benefits derived from the services provided by any particular ecosystem, the more that ecosystem is valued by society. In general, the value of these services tends to be positively related with the integrity of the ecosystem. Of course, any action taken to decrease the loss of Louisiana's coastal wetlands, and thus increase the welfare of society at large, comes with a cost. These costs must be weighed against the benefits to determine, from the criteria of welfare economics, whether specific restoration or preservation actions are warranted, and to what extent.

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[8] While significant nonrenewable mineral extraction, and the related economic activity, takes place in coastal Louisiana and the adjacent continental shelf, to a large extent its continued existence is not dependent on maintaining the integrity of the coastal wetlands. The extraction industry's cost structure may change if coastal wetlands are lost, but not likely to the extent that they would become economically infeasible. Navigation and port activities, however, are more likely to be negatively affected by the loss of coastal wetlands.

Valuation Methods

The total economic value of a wetland area is the sum of the amount of money that all people who benefit from the wetland area would be willing to pay to see it protected (Whitehead 1992). If this definition of wetland value is to be empirically viable, individuals that benefit must (1) realize that they benefit, (2) understand the full extent to which they benefit, and (3) be capable of placing a dollar value on the level of their benefits, either through reference to market-based prices or some alternative, nonmarket pricing system. Methods for valuing the stock of natural capital assets and service flows generated by wetlands have been extensively discussed in both the published and unpublished literature.[9] While philosophical debate has occurred over the ability to empirically measure the full range of benefits that flow from an environmental resource, economists generally agree that accurate measurement is possible if valuation studies are carefully conducted (U.S. Department of Commerce 1993). In fact, review of past nonmarket valuation studies suggests that previously perceived variability and unreliability in the estimated values does not actually exist, particularly if one controls for the varying characteristics of the resources being valued and the way in which the estimated values are presented (Carson et al. 1996). Thus, published value estimates might be useful in analyzing the economic impact of Louisiana's coastal wetlands as long as careful attention is given to the details of the study and the resources being valued.[10]

Four theoretically plausible valuation methods have been used in the neoclassical economic literature to place valid dollar values on wetland resources.[11] These methods are the net factor income (NFI) method, the contingent valuation method (CVM), the travel cost method (TCM), and the hedonic price method (HPM). A fifth set of methods found in the literature, but not theoretically valid under typical application, is the damage cost or replacement cost methods (DCM or RCM). All of these methods are briefly described below. In addition, the non-neoclassical literature, as well as the biological literature, often contains studies employing energy analysis methods (EAM), whereby the value of ecosystem assets are directly related to their energy processing abilities.[12] Shabman and Batie (1978) detailed the fundamental problems and economic fallacies imbedded in this approach,[13] and no further discussion of its use is included in this report. The results from two studies employing EAM, however, are reported in Table 2 in order to completely characterize the wetland valuation literature.

The NFI method uses market prices to measure the additional profit earned by firms due to the contribution of the wetlands to production activities, and it generates use values. Thus, the NFI method is most appropriate when the wetland provides a service that leads to an increase in producer surplus, or the

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[9] For excellent early overviews, see Greenley et al. (1982) and Amacher et al. (1989). Scodari (1990) provides a thorough review of the advantages and disadvantages of various methods specifically within a wetland valuation context, while Whitehead (1992) contains a lucid, if somewhat terse, review of the methods and the theory behind them. More recent papers detailing established and newer methods include Feather et al. (1995), Apogee Research, Inc. (1996), Mahan (1997), Bockstael (1998) and Pendleton and Shonkwiler (2001). For comprehensive reviews of the theory and application of contingent valuation methods for nonmarket goods and services, see U.S. Department of Commerce (1993) and Bishop et al. (1998).

[10] This type of detailed examination was beyond the time constraints of this study, but it should be seriously considered for inclusion in future phases of a valuation project.

[11] The brief methods discussion borrows from Amacher et al. (1989), Whitehead (1992), and others.

[12] This approach, which first received widespread publicity and policy attention due to a study by Gosselink et al. (1974), is based on the Odum and Odum (1972) contention that society's use of resources should maximize the net energy production of the total environment (including its natural and developed components).

[13] The fundamental problem is that EAM fails to recognize the nature of the process by which economic values are determined, and makes an "illegitimate marriage" of the principles of systems ecology with economic theory (Shabman and Batie 1978). "This leads to estimates of marsh service value that are, at best, inaccurate. At worst, these inaccurate estimates may capture the focus of policy debate, and hinder, rather than improve, the resource management process for coastal wetlands."

economic gains attained by the users of the resource, because it exploits the relationship between the value of the production activity and the wetland acreage. In the NFI method the physical relationship between wetland areas and the economic activity is empirically estimated from data on the production activity. It is then possible to identify the increase in producer surplus (economic gain) associated with the use of the wetland resource.[14] If the empirical estimates are obtained through statistical regression, then estimates of the marginal value product (MVP) of the wetland resource can be generated. In this context, the MVP provides a direct measure of the firm owner's willingness-to-pay to avoid wetland degradation.

Producer surplus generated by the use of a wetland can also be estimated using the RCM. This approach values the wetland=s service based on the price of the cheapest alternative way of obtaining that service. For example, the value of a natural wetland in the treatment of wastewater might be estimated using the cost of chemical, mechanical, or constructive alternatives. The use of RCMs needs to be governed by three considerations (Shabman and Batie 1978): (1) the alternative considered should provide the same services, (2) the alternative selected for cost comparison should be the least-cost alternative, and (3) there should be substantial evidence that the service would be demanded by society if it were provided by that least-cost alternative.[15] Taken together, these condition differentiate RCM from the more general class of DCMs, where the entire value of a marketable good or service is tied to the preservation of a wetland resource, ignoring consumer and producer substitution possibilities. Even with restrictive application, the RCM can only be considered to yield an upper bound on the true WTP for the wetland service because the producer may not choose to actually use the alternative considered (Anderson and Rockel 1991).

The CVM is a survey approach that measures the total economic value of all wetland goods and services by directly asking individuals about their WTP. The CVM establishes a hypothetical market by providing information about wetland resources, specifying payment rules and vehicles, and posing valuation questions. Answers to these questions can be used to directly measure WTP, and CVM may be the only way to estimate many non-use values of environmental resources. But, in order for CVM to yield valid economic measures, study participants must be both willing and able to reveal their values. Other valuation approaches, such as TCM and HPM discussed below, depend on revealed preferences through market transactions and other behavior. Statements from economic actors about how they would act under hypothetical circumstances, as used in the CVM, are a very different measure and ultimately need to assessed for validity (Bishop et al. 1998). A panel of experts organized by the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, and co-chaired by Nobel laureate economists Kenneth Arrow and Robert Solow, concluded that (1) there is too much positive evidence to dismiss CVM and its usefulness in providing information about values, (2) CVM studies do not automatically generate value information, but are highly dependent on the content validity of the survey, and (3) CVM is an evolving market valuation technique (U.S. Department of Commerce 1993). In the words of the panel (p. 4610), "CV studies convey useful information. We think it is fair to describe such information as reliable by the standards that seem to be implicit in similar contexts, like market analysis for new and innovative products and the assessment of other damages normally allowed in court proceedings . . . . Thus, the Panel concludes that CV studies can produce estimates reliable enough to be a starting point of a judicial process of damage assessment, including lost passive-use values."

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[14] In practice, it is often assumed that the demand for the good being produced by the water user is perfectly elastic, and thus changing wetland services has no effect on consumer surplus.

[15] For example, suppose that 90 pounds of nitrogen could be removed from freshwater each year by an acre of coastal marshland (as is typical for the Caernarvon freshwater diversion of the Mississippi River in Louisiana -- see Mitsch et al. 1999, p. 88), at a cost savings of $100 per year (an entirely arbitrary value) when compared to the cost of treatment plant removal. If the marsh acre does not actually receive the waste load, than no dollar benefits for waste assimilation exist. Furthermore, to properly apply this approach the variable waste assimilation capacities of different types of coastal marshland would need to be accounted for in the analysis.

The TCM approach is often used to measure the recreational benefits of wetlands, but it is generally applicable to valuing any nonmarket wetland good or service that individuals are willing to travel to and use at the wetland site. The TCM method estimates the costs incurred traveling to visit and use the site, with the concept being that the travel and time costs are measures of implicit market prices. The estimated costs are then used to construct demand functions that use travel and time costs as independent variables.[16] Consumer surplus per recreation trip and year can then be approximated from the estimated demand curve. The application of TCM assumes that (1) users have identical utility functions for the activity, and thus will have identical demand functions, (2) users are indifferent between incurring costs as user fees or travel costs, (3) weak complimentarity holds in that changes at competing sites do not affect use at the site being valued, and (4) site use is not congested. Given these assumptions, TCMs cannot be used to value nonmarket goods and services that either do not require the user to visit the site or that are offsite products. Furthermore, TCM generally cannot account for multiple sites, visits to multiple sites on the same trip, or the impact of small resource changes on user perceptions and travel patterns.

The HPM has been used to measure the contribution of wetlands for flood control and the role of wetland aesthetics in housing and property prices. Thus, HPMs attempt to tie wetland service value directly to a market price (Freeman 1998). In a market at equilibrium, land values and land rents should be a function of land characteristics, including the proximity to and services provided by wetlands. The increment to the land or housing price arising from wetland services is a measure of the implicit price of that service. There are three key assumptions required to apply HPM to estimate the wetland contribution to land values. First, there must be data on a continuum of sites with varying wetland characteristics and acreage. Second, purchasers and sellers of wetland parcels are assumed to have access to the same information regarding the condition of the site and the nature and use of the wetland. Third, wetland purchasers (or purchasers of property near wetlands) are assumed to have identical preferences for wetland characteristics. The assumption of identical preferences makes estimation of demand curves possible when data does not exist about individual preferences.

The valuation method employed in any particular water quality study depends primarily on the ability to quantitatively discern the biophysical linkages between characteristics of a particular wetland area and the change in the quality of water as it moves through the area. In cases where this relationship is well understood, NFI methods can be employed. In cases where the biophysical linkages are not well described, but the demanded water quality can be defined, then RCM or CVM may be most appropriate even in light of their limitations. No water quality service value studies were found that employed TCM or HPM approaches. Of course, the choice of a particular measurement method is important and can have implications for the estimated value of a wetland area. For example, in a meta-analysis of wetlands valuation studies, Woodward and Wui (2000) discovered that NFI methods tended to generate lower estimated values for wetlands than did RCM. This confirms the Anderson and Rockel (1991) observation that RCM should generate an upper bound on actual value.

Review of Estimated Values

Peer-reviewed literature estimates of the water quality service values generated by an acre of wetland are presented in Table 1. Four different categories of studies were identified; Louisiana specific studies, other U.S. studies, international studies, and studies that did not report their results on an area basis (primarily CVM based WTP studies). In addition, peer-reviewed literature estimates of total service

[16] Other independent variables are also employed, including the theoretically requisite income and various potential demand shifters, depending on the situation being modeled.

values generated by an acre of wetland were arranged by the same four categories and are presented in Table 2. The overall service value estimates are potentially useful when evaluating a study, as individually disaggregated service values should (obviously) never exceed total service value. In fact, individually disaggregated service values, when summed across all service categories, also should not exceed total value. In any event, the total values are included in the report to help the reader gain a broader understanding of the information available in the valuation literature.

Reported estimates for the value of Louisiana wetlands in the provision of water quality services ranged from a low of $2.85/acre/year to a high of $5,673.80/acre/year, with a mean and median value of $975.01/acre/year and $281.24/acre/year, respectively (Table 1).[17, 18] Given that all the Louisiana-specific studies used the same RCM approach, the disparity in valuation can be strictly linked to differing site characteristics, the specific water quality service being demanded, and (in the case of the lowest estimated value) whether localized benefits were calculated to extend across all existing wetlands in the coastal zone. This latter approach substantial underestimates the potential water quality service value of wetlands near municipalities and industries that might use them for tertiary treatment of wastewater, while at the same time overestimating the water quality service value of wetlands not located near municipalities (and thus likely to provide zero wastewater processing benefits). In a similar way, the water quality service value of wetlands for industrial wastewater tertiary treatment in Louisiana might be extremely high at a specific location (for example, the $5,673.80/acre/year for processing a potato chip plant's effluent), but the benefits are restricted to a very small number of acres. The apparent importance of geographic location and localized use demands on water quality services suggests that single estimate of this service value should not be used in any kind of economy-wide analysis. Instead, efforts need to be made to identify, as closely as possible, the spatial distribution of current, and possible potential, water quality service use demands. This information would be very useful in prioritizing wetland restoration and preservation activities, particular with respect to wastewater treatment services and associated joint-products of wetland functions.

Studies conducted for wetlands in other regions of the U.S. reported water quality service values that ranged from $88.64/acre/year to $2,687.59/acre/year, with a mean and median value of $513.99/acre/year and $165.24/acre/year, respectively (Table 1). These estimates fell within the range of values reported specifically for Louisiana, although the mean and median values were substantially lower. This occurred even though most of the other estimates were conducted for coastal wetlands in similar climatic conditions.[19] A limited number of international studies also reported water quality service values well within the range of those reported for Louisiana, with estimates varying between $98.72/acre/year and $1,963.68/acre/year (mean and median values of $720.57/acre/year and $99.31/acre/year, respectively). The difference between the international studies and values for Louisiana might be expected, however, given the differences in the types of wetlands being valued and their location. Considering only coastal zone wetlands across all study categories (Louisiana, other U.S., and international), the value of water quality services ranged from $2.85/acre/year to $5,673.80/acre/year, with a mean and median of $825.04/acre/year and $210.93/acre/year, respectively. The large difference between the mean and median value reflects the non-normal distribution of the aggregated estimates, and in particular the influence of a

[17] All values in year 2000 dollars.

[18] It should be emphasized that all of the reported Louisiana valuation studies were conducted by one set of authors in a very specific time period. The importance of this information to understanding the value of water quality services derived from Louisiana wetlands is not clear, although it is always preferable to have multiple, independent studies on which to base inferences.

[19] The importance of climate, and its relationship to the maximum level of waste processing that can be obtained from a given wetland, is intimately linked to the maximum value that can be expected from wetland water quality services. This can be seen by noticing the relationship of site location and value in both Tables 1 and 2 (although, given varying valuation measures, the relationship is not perfect).

few very high values. Eliminating the most extreme outliers from the calculations generated mean and median values of $323.05/acre/year and $178.64/acre/year, respectively.

For comparison purposes, reported estimates of willingness-to-pay (WTP) values for wetland water quality services ranged from a low of $41.71 to $101.81, with a mean and median of $66.59 and $63.19, respectively (Table 1). Two things are particularly interesting about these estimates. First, the variability among the estimates is substantially lower than the estimates generated with other valuation methods (primarily RCM). Given that RCM measures very site and use demand specific values for water quality services, it appears that CVM approaches to valuing water quality services may be measuring a generalized WTP that incorporates the probability of any given tract of wetland being used for water purification. Alternatively, the CVM studies may be measuring a completely different water quality service compared to the specific wastewater treatment services that were calculated in the RCM studies. In particular, the values derived from the CVM studies may be related to a WTP for a generalized water quality service that maintains the functioning of the larger coastal ecosystem. Whether the former, latter, or some other explanation applies may only be determined by a detailed examination of the studies, their methods, and especially their survey design.

Given the widely varying estimates of water quality service values, and the apparent site and use specific reasons for the variability, this facet of coastal wetland benefits needs to be carefully examined within a spatially disaggregated context. Barring a spatially disaggregate study, a conservative approach to incorporating coastal wetland water quality services into a generalized impact analysis might be to utilize the WTP estimates found in the literature to calculate an annualized acreage value. The best way to approach this would be to examine each reported study for information that would allow generalization of the household WTP to actual land areas given user and nonuser populations. This approach was attempted for a number of studies by Heimlich et al. (1998), but with somewhat limited success due to problems with assumptions made by the authors. If such a detailed approach is not feasible, then it might be acceptable to take advantage of the remarkable consistency of reported WTP values across all types of wetlands (particularly in comparison to the non-WTP estimates) and their approximately normal distribution to estimate a defensible "average" value for coastal wetland water quality services. For example, assuming 3.5 million acres of coastal wetlands in Louisiana,[20] a coastal population of 2.05 million,[21] and a mean WTP of $66.59,[22] the annualized value of water quality services for coastal Louisiana would be approximately $39/acre/year.

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[20] Source: Louisiana Coastal Restoration Web Site at http://www.lacoast.gov/wetlands/overview/justification.htm

[21] Source: NOAA at http://www.ocrm.nos.noaa.gov/czm/czmlouisiana.html

[22] The WTP studies reported water quality service values on a per individual and per household basis. This calculation assumes the mean WTP can be applied to each individual, and that the individuals would be willing to pay this amount on an annual basis. Note also that no coast-specific WTP studies were found in the literature.

Table 1. Published estimates of water quality service values provided by wetlands, 1981-2001.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					Louisiana Specific Studies						
Farber 1996	Entire Louisiana coast	Coastal wetlands	Tertiary municipal wastewater	23.7 million	Cost savings (based on Breaux et al. 1995)	3	93	1990	1,425,000	2.16[b]	2.85
Breaux et al. 1995	Thibodaux, Louisiana	forested swamp	tertiary municipal wastewater	570	cost saved vs conventional; with chlorination	9	30	1990	448,000	76.50	100.79
Breaux et al. 1995	Thibodaux, Louisiana	forested swamp	tertiary municipal wastewater	570	cost saved vs conventional; with ultraviolet	9	30	1990	504,000	86.07	113.40
Breaux et al. 1995	Thibodaux, Louisiana	forested swamp/ bottoms	tertiary municipal wastewater	570	cost saved vs conventional; ultraviolet vs conv. chlorinates	9	30	1990	800,000	136.61	179.99
Breaux et al. 1995	Thibodaux, Louisiana	forested swamp/ bottoms	tertiary municipal wastewater	570	cost saved vs conventional; only conv. chlorinates	9	30	1990	1,250,000	213.46	281.24
Breaux et al. 1995	Thibodaux, Louisiana	forested swamp/ bottoms	tertiary municipal wastewater	570	cost saved vs conventional; only conv. ultraviolet	9	30	1990	1,310,000	223.70	294.73
Breaux et al. 1995	Dulac, Louisiana	coastal wetland	tertiary seafood plant wastewater	2860	cost savings for 15 plants - lower bound (small plant) estimate	9	25	1990	17,820,000	634.33	835.74
Breaux et al. 1995	Dulac, Louisiana	coastal wetland	tertiary seafood plant wastewater	2860	cost savings for 15 plants - upper bound (large plant) estimate	9	25	1990	27,560,000	981.04	1,292.54
Breaux et al. 1995	Grammercy, Louisiana	Hard-wood bottoms	tertiary chip plant wastewater	6.2	cost savings for one small manufacturer	9	15	1990	215,220	4,306.44	5,673.80

Table 1. Published estimates of water quality service values provided by wetlands, 1981-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					Additional U.S. Studies						
Fritz et al. 1984	Orlando, Florida	Cypress dome	Tertiary municipal wastewater	790.72	Cost savings over conventional - with buffers	6	20	1976	265,659	29.29	88.64
Fritz et al. 1984	Waldo, Florida	Wetland	Tertiary municipal wastewater	65.49	Cost savings over conventional - with buffers	6	20	1976	22,958	30.56	92.99
Fritz et al. 1984	Orlando, Florida	Cypress stand	Tertiary municipal wastewater	790.72	Cost savings over conventional - with buffers	6	20	1976	362,411	39.96	120.93
Fritz et al. 1984	Waldo, Florida	Wetland	Tertiary municipal wastewater	39.54	Cost savings over conventional - no buffers	6	20	1976	22,958	50.62	153.19
Fritz et al. 1984	Orlando, Florida	Cypress dome	Tertiary municipal wastewater	395.36	Cost savings over conventional - no buffers	6	20	1976	265,659	58.58	177.28
Fritz et al. 1984	Orlando, Florida	Cypress stand	Tertiary municipal wastewater	395.36	Cost savings over conventional - no buffers	6	20	1976	362,412	79.92	241.87
Woodward and Wui 2001	-----	Mixed	General water quality	-----	Econometric meta-analysis of 39 studies yielding per acre values; excludes WTP where per acre value was not generated	-----	-----	1990	-----	417 90% C.I. of 126 - 1,378	549.41
Thibodeau and Ostro 1981	Charles River Basin	Costal wetlands	Tertiary municipal wastewater	8,535	Cost savings over conventional	6	Infinite	1978	16,960	1,017.60	2,687.59
					International Studies						
Gren et al. 1995	Danube floodplain	Mixed	Reduced nitrogen and phosphorus	4.3 m	Non-WTP date derived from Gren 1993, Elofsson 1993, and Haskoning 1994	-----	-----	1991	-----	85.80 ecu[c]	98.72

Table 1. Published estimates of water quality service values provided by wetlands, 1981-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					International Studies						
Gren 1999	Baltic Sea drainage basin	All wetlands	Nitrogen sink for 50% reduction	-----	Non-linear national cost minimization under a doubling of wetland acreage scenario	-----	-----	1998	-----	94[d]	99.31
Costanza et al. 1997	World wide	Coastal wetlands	Waste treatment	815 m world wide	Mixed aggregation of various studies; little detail given concerning specific studies	-----	-----	1994	-----	1,690	1963.68
					Studies Where Value Not Reported on an Area Basis						
Mathews 1999	Minnesota	River	Reduce phosphorus loads by 40 percent	-----	WTP contingent valuation and travel cost in a combined model	-----	-----	1997	-----	38.88[g]	41.71[g]
Farber and Griner 2000	Pennsylvania	Streams	Quality increase - moderate to unpolluted	-----	Conjoint, random utility model	-----	-----	1996	-----	38.59[e g]	42.35[g]
Lant and Roberts 1990	14 towns in Iowa and Illinois along border	Riverine wetlands	Quality increase - poor to fair	-----	WTP contingent valuation adjusted for non-response bias	-----	-----	1987	-----	37.61[f g]	57.01[g]
Farber and Griner 2000	Pennsylvania	Streams	Quality increase - severely to moderately polluted	-----	Conjoint, random utility model	-----	-----	1996	-----	55.46[e g]	60.87[g]
Lant and Roberts 1990	14 towns in Iowa and Illinois along border	Riverine wetlands	Quality increase - good to excellent	-----	WTP contingent valuation adjusted for non-response bias	-----	-----	1987	-----	43.22[f g]	65.51[g]

Table 1. Published estimates of water quality service values provided by wetlands, 1981-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					Studies Where Value Not Reported on an Area Basis						
Lant and Roberts 1990	14 towns in Iowa and Illinois along border	Riverine wetlands	Quality increase - fair to good	-----	WTP contingent valuation adjusted for non-response bias	-----	-----	1987	-----	47.16[f g]	71.49[g]
Stevens et al. 1995	New England	Wetlands in general	Pollution control combined with flood protection and water supply	-----	WTP contingent valuation mail survey	-----	-----	1993	-----	77.15[g]	91.94[g]
Farber and Griner 2000	Pennsylvania	Streams	Quality increase - severely to unpolluted	-----	Conjoint, random utility model	-----	-----	1996	-----	92.76[e g]	101.81[g]

[a] Study values inflated to common year 2000 values using the Bureau of Labor Statistics (BLS) CPI Inflation Calculator, which bases yearly adjustments on the average consumer price index by year.
[b] Author spread the cost savings across all projected wetland acres lost through 2083; insufficient data reported to calculate the cost savings just on acres lost that might be used in waste treatment.
[c] Inflated to year 2000 using the BLS CPI Inflation Calculator and converted to U.S. dollars using the ratio 1.10ecu/$1.00
[d] Value represent the simple average for 8 Baltic countries reported in Gren (1999). Germany, reported on in the article, was excluded from the simple average because of the extreme estimates ($1,778/acre/yr) resulting from a complex interaction with atmospheric deposition of nitrogen. The range of values is primarily due to different climatic conditions, and thus wetlands processing ability, in the different countries. See Gren (1999) for more details.
[e] Authors estimate multiple user, nonuser, and combined models in both dichotomous and multiple choice formats; values reported represent the best statistical estimates for a combined user model.
[f] Authors also examined the potential for strategic bidding and rejected the hypothesis based on distributional relationship of bids to respondent income.
[g] Value is not reported on a per acre per year basis. In most cases, the value represents household willingness-to-pay for the service where the service/wetland quantity relationship is not defined.

Table 2. Published estimates of total service values provided by wetlands, 1975-2001.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					Louisiana Specific Studies						
Costanza and Farber 1987	Terrebonne Parish, Louisiana	Coastal Louisiana	Summation of commercial fishing, trapping, recreation, and storm protection	650,000	Simple summation of mixed method estimates of individual services	8.0	Infinite	1983	586.73	46.94	81.16
Costanza et al. 1989	Louisiana	Coastal wetlands	Commercial fishing, trapping, recreation, and storm protection	-----	Production function, revenue accounting, travel cost, and WTP contingent valuation	8.0 , 3.0	Infinite	1983	2,429 - 8,977	194.32[b]	335.96
Costanza and Farber 1987, Costanza et al. 1989	Terrebonne Parish, Louisiana	Fresh coastal wetlands	All services	650,000	Energy analysis based gross primary productivity conversion, net value lost when converting wetland to open water	8.0	Infinite	1983	6,400	512.00	885.20
Costanza and Farber 1987	Terrebonne Parish, Louisiana	Saltwater coastal wetlands	All services	650,000	Energy analysis based gross primary productivity conversion, net value lost when converting wetland to open water	8.0	Infinite	1983	6,700	536.00	926.70
Costanza and Farber 1987	Terrebonne Parish, Louisiana	Brackish coastal wetlands	All services	650,000	Energy analysis based gross primary productivity conversion, net value lost when converting wetland to open water	8.0	Infinite	1983	10,602	848.16	1,466.40

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
Additional U.S. Studies											
van Vuuren and Roy 1993	Lake St. Clair, Michigan & Canada	Freshwater wetlands	Public and club hunting, angling, trapping	741 undiked	Travel cost	4.0	50	1985	4,435	83.55	133.71
Gupta and Foster 1975	Massachusetts	LLNN Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	500	40	165
van Vuuren and Roy 1993	Lake St. Clair, Michigan & Canada	Freshwater wetlands	Public and club hunting, angling, trapping	370.7 diked	Travel cost	4.0	50	1985	6,027	113.54	181.71
van Vuuren and Roy 1993	Lake St. Clair, Michigan & Canada	Freshwater wetlands	Public and club hunting, angling, trapping	49.4 diked	Travel cost	4.0	50	1985	6,968	131.27	210.08
Roberts and Leitch 1997	Mud Lake, MN-SD	Fresh wetland	All services	-----	Cost savings, residual return to water utilities, contingent valuation	-----	-----	1995	-----	375	423.72
Gupta and Foster 1975	Massachusetts	HLNN Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	1,400	113	466
Gupta and Foster 1975	Massachusetts	LLNH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	1,700	137	564

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					Additional U.S. Studies						
Gupta and Foster 1975	Massachusetts	MMNM Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	3,000	242	997
Gupta and Foster 1975	Massachusetts	LHNL Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	4,100	330	1,359
Gupta and Foster 1975	Massachusetts	HHNH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	6,000	484	1,994
Gupta and Foster 1975	Massachusetts	LLLL Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	6,400	519	2,138
Gupta and Foster 1975	Massachusetts	HHLH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	11,700	943	3,885

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
Additional U.S. Studies											
Gupta and Foster 1975	Massachusetts	HHMH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	26,000	2,095	12,750
Gupta and Foster 1975	Massachusetts	LLHL Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	40,700	3,280	13,512
Gupta and Foster 1975	Massachusetts	HHHH Wetland	Benefits of wildlife, visual/cultural, water supply, and flood control	-----	Average state acquisition price scaled by habitat score (wildlife) or quality (visual cultural), 1971 ACE study of Charles River (flood control), 1970 USGS study (supply)	7.0	30	1972	46,000	3,707	15,271
Thibodeau and Ostro 1981	Charles River Basin	Costal wetlands	All services	8,535	Simple summation of mixed method estimates of individual services	6	Infinite	1978	171,772	10,306.32	27,220
International Studies											
Gren et al. 1995	Danube floodplain	Mixed	All ecosystem services	4.3 m	Summation of individual service estimates	5.0 and 2.0 percent	infinite	1991	3,027 ecu to 7568 ecu per acre	151.35 ecu	174.13[c]
Costanza et al. 1997	World wide	Coastal wetlands	All services and products	815 m world wide	Mixed aggregation of various studies; little detail given concerning specific studies	-----	-----	1994	-----	5,983	6,952

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
Studies Where Value Not Reported on an Area Basis											
Sathirathai and Barbier 2001	Thailand	Mangrove wetland	Direct and indirect use (timber, fishing, coastline protection)	988	various	-----	-----	1993	-----	1,553[de]	1,851[e]
Mullarkey and Bishop 1999	Northwest Wisconsin	Fresh wetland	Total value under high certainty	110	WTP mail survey; respondent certainty and scope test included	-----	-----	1995	-----	20.77[e]	23.47[e]
Mullarkey and Bishop 1999	Northwest Wisconsin	Fresh wetland	Total value under low certainty	110	WTP mail survey; respondent certainty and scope test included	-----	-----	1995	-----	57.83[e]	65.34[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of Oregon residents	-----	-----	1989	-----	67.80[e]	94.15[e]
Loomis et al. 2000	Nebraska	Platte River	Wastewater dilution, water purification, erosion control, habitat, and recreation	300,000	WTP mail survey	-----	-----	1998	-----	252[e]	100.79[e]
Stevens et al. 1995	New England	General wetlands	Recreation, rare species, food production, flood protection, water supply and pollution control	-----	WTP contingent valuation mail survey	-----	-----	1993	-----	114.29[e]	136.20[e]

Table 2. Published estimates of total service values provided by wetlands, 1975-2001 -- continued.

Study	Location	Site Type	Site Use	Site Size (acres)	Valuation Method	Discount Rate (%)	Time Horizon (years)	Base Year	NPV Estimate (base yr $)	Annualized Value/Acre (base yr $)	Annualized Value/Acre (yr 2000 $)[a]
					Studies Where Value Not Reported on an Area Basis						
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of Washington residents	-----	-----	1989	-----	99.75[e]	138.52[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of Nevada residents	-----	-----	1989	-----	196.01[e]	272.20[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey California residents outside the San Joaquin Valley	-----	-----	1989	-----	210.77[e]	292.70[e]
Pate and Loomis 1997	San Joaquin Valley, CA	General wetlands	Generalized to all uses	90,000	WTP mail survey of San Joaquin Valley residents	-----	-----	1989	-----	215.55[e]	299.34[e]

[a] Study values inflated to common year 2000 values using the Bureau of Labor Statistics (BLS) CPI Inflation Calculator, which bases yearly adjustments on the average consumer price index by year.
[b] Storm protection accounted for 79 percent ($153.20/acre/yr) of the total value.
[c] Inflated to year 2000 using the BLS CPI Inflation Calculator and converted to U.S. dollars using the ratio 1.10 ecu/$1.00 U.S.
[d] Value is strongly influenced by estimates for coastline protection, which account for 96% of the total.
[e] Value is not reported on a per acre per year basis. In most cases, the value represents household willingness-to-pay for the service where the service/wetland quantity relationship is not defined.

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